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Multi-agent systems applied to reliability assessment of power systems

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ABSTRACT

This paper discusses the development of a Multi-Agent Systems (MAS) technology-based platform with potential applications in management and simulation processes in power systems. In order to explore some of the features of MAS, a new methodology is proposed to assess power systems reliability based on Monte Carlo simulation (MCS), exploiting the benefits of the distributed artificial intelligence area and, mainly, the use of the distributed capacity in two ways: building autonomous behaviors to the applications and mitigating computational effort. Through the use of this technology, it was possible to divide the MCS algorithm into distinct tasks and submit them to the agents' processing. Two different approaches to solve generating capacity reliability problems based on chronological MCS illustrate the potential of MAS in power systems reliability assessment.

1. Introduction

In artificial intelligence (AI) research, agent-based systems technology is a new paradigm for conceptualizing, designing, and implementing software systems. Intelligent agents are sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems. Increasingly, however, applications have required multiple intelligent agents (IA) that can work together. A multi-agent system is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver.

Several technical works using MAS technology have been published in the literature [1–7], showing potential applications to solve problems related with electric power systems. Recently, two important contributions have organized the concepts, approaches, technical challenges, technologies, standards, and tools for building MAS applied to power engineering [1,2]. Many aspects were discussed in relation to the benefits of this technology besides providing guidance and information on the state-of-the-art of MAS research for the power industry. Some favoured issues in power agent applications have been indicated: modelling, simulation and distributed control. In particular, the modelling of electricity market as a complex adaptive system [3] and the optimization of decisions in retail markets [4] have been discussed. In the last few years, some other applications were carried out to solve power engineering problems [1,2] such as systems integration with database, systems and equipment monitoring, interpretation and analysis of outage data, system restoration [5], support to decision in micro-grids operation [6], and environment simulation [7]. These approaches have shown the great potential of MAS, exploring the concepts of communication and autonomous behaviors offered by this technology. In order to explore some other features of the MAS technology, an application to power systems reliability assessment is being proposed in this work. It uses the benefits from the distributed artificial intelligence area in two ways: building autonomous behaviors and reducing computational effort on power systems reliability evaluations.

Many works have explored the use of the distributed or parallel environment in power systems evaluations [8–10], some of them including reliability assessment [8]. Different from these works, which generally aim mitigating computational effort and make feasible some expensive simulations, this work intends to build a software environment where agents are capable of sensing it through the use of basic intelligence offered by the agent-based technology. This environment facilitates the agents to recognize others specific agents, within the platform, as well as to promote communication among them through the use of *performative* structures. In order to introduce computational intelligence in power system reliability assessment, MAS using Java technology is being proposed, where the agent base is supported by distributed computing technology [11,12].

This paper discusses the development of a MAS technology-based platform to assess generating capacity reliability indices,

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based on sequential or chronological MCS processes. Although the focus will be on the application of MAS to this particular reliability problem, other applications based on simulation can also be benefited in a similar manner. The MAS construction was designed under the concept of reliability assessment by the sequential MCS. JADE Library (Java Agent Development Framework) [13], standardized by FIPA (Foundation Intelligent Physical Agents: www.fipa.org), is used and, sometimes, only Java language is called for constructing agents. In the next sections, one will present an overview of the power agent platform, the application of MAS in power systems reliability assessment based on two different approaches, and the results of the reliability evaluations of two electric systems: the IEEE-RTS, with 32 unit generators, and a modified configuration of the Brazilian South/South-eastern System (BSS), with 242 unit generators. Discussions will be provided to demonstrate the potential of MAS technology.

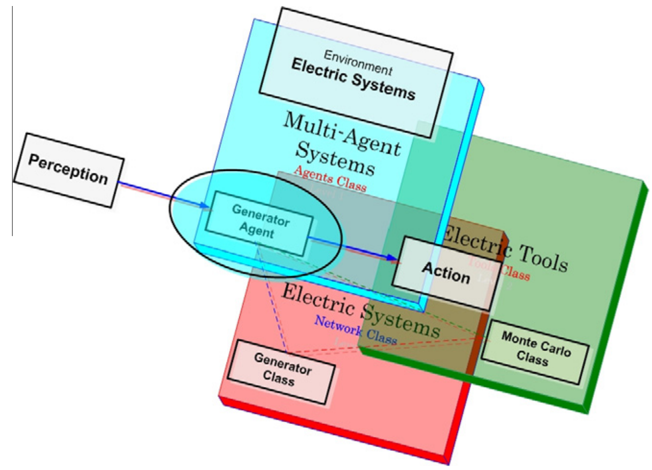

Fig. 1. Representation of the platform layers.

2. Overview of the power agent platform

The proposed power agent platform can be described through layers, as shown in Fig. 1. In the first level, at the bottom (in red[1]), there is the class diagram that represents the electric power system. Representations such as generators, transmission lines, distribution network, and buses have a relationship among them, based on the Oriented Object Modeling (OOM). In the second level, at the right side (in green), there is the class diagram named *tools class* that represents the tools linked to each evaluation algorithm, such as reliability assessment by a sequential MCS. In the third level, at the top (in blue), there is the class diagram with the MAS technology, where agents are built and provided with some abilities to use the first and the second levels, previously described. Fig. 1 is also showing a *Generator Agent* using the *Monte Carlo Class* and the *Generator Class*, which after a perception on its specific environment, has taken an action. Obviously, this simple representation intends to show the philosophy of the simulation platform using one of the main characteristic of agents: autonomy.

In a simpler sense, an agent can be classified as software or hardware elements located in a specific environment, which is able to note changes and react to these changes [14]. Following the same idea, power engineers can compare this concept with an old and simple well-known agent: an over-current relay, which after its perception about an over-current will take an action, switching off the electric circuit. Characteristics such as *Reactivity*, *Pro-Activity* and *Social Ability* are described in several references on Artificial Intelligence (AI) and MAS [14], and here they are applied to this proposed simulation platform. Essentially, the MAS technology is the combination of these inherent characteristics and others that allows its clear distinction from other conventional tools in the power systems analysis. One of the most important characteristics of this technology appears as applying Java to build agents with its ability to distribute applications and run concurrency programming. This feature enables the building of power models using intelligent behaviors in a very distinctive way.

3. Reliability assessment using MAS

The reliability assessment of real large power system by sequential MCS is known as being a very expensive computational evaluation. Moreover, to analyze the sampled states, heavy computational tools such as optimal power flows are intensively used [8,15]. The solution time for analytical techniques is relatively short, but usually requires a simplification of the systems [16]. However, sequential MCS makes possible the use of a wide range of detailed models including non-Markovian representation for generation and transmission equipment, correlated chronological load models, etc. In order to reduce this expensive computational cost, different techniques have been proposed: distributed processing [8], artificial neural networks [15], variance reduction [17,18], pseudo-chronological simulations [19]. There are other related techniques to reduce CPU costs that can be found in the bibliography lists of the previous references.

3.1. Using IA to support AI in power system reliability assessment

The Monte Carlo technique is a statistical-based method which can be naturally divided in three inherent stages, in order to assess reliability indices: state selection, state evaluation and index calculation. Many works have explored AI topics as search techniques, knowledge representation, reasoning and learning systems as well as some mathematical approaches aiming to incorporate intelligence on these stages [15,20,21]. Generally, these approaches appear as competitors with non-sequential Monte Carlo simulation, in order to achieve a more efficient simulation process. Fig. 2 shows an overview of these representations. This paper intends to construct an agent-based application in order to support the natural transition from AI to IA in power system reliability assessment. The main idea is to construct a basic intelligent distributed environment that can be able to support sequential Monte Carlo representation using IA features.

Instead of applying AI techniques in order to improve a single stage of non-sequential MCS, this work intends to build an IA architecture that supports sequential MCS as well as AI techniques in more than one stage of the simulation process. Consequently, it will be possible to measure the gains of an agent-based distributed structure in reliability assessment before applying AI topics, using an intelligent agent architecture design. Different from a simple distributed approach, which uses signals to control computers inside a network [8], this work uses agent communication language (KQML: Knowledge Query and Manipulation Language) [13] in order to establish communication among agents. KQML is essentially a knowledge-level message language, which defines a number of performatives and makes explicit an agent's intentions [14]. Firstly, the aim is combining KQML with autonomous behaviors of each stage of the sequential Monte Carlo representation to define an IA architecture design. Secondly, it will prepare this IA architecture to support different AI techniques.

[1] For interpretation of color in Figs. 1, 4, 6–8, the reader is referred to the web version of this article.